# THE CASE OF HAITI. IMPACT ANALYSIS: IDENTIFICATION OF CRITERIA AND DESCRIPTORS

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## SUMMARY

Haiti's cataclysmic earthquake caused 300 000 deaths, left this capital in ruins and sent more than a million people into a life in crowded and squalid camps.
As the world's population becomes increasingly concentrated in large cities, an intensification of risk is being observed. A disaster-prone urban future should be avoided: we urgently need a "disaster-free" urbanization which can be achieved with good policies and practices in urban development.
In this paper besides presenting the general impact of the earthquake and discuss the main reasons for this catastrophe, we present a new methodology for impact analysis based on identification of criteria and descriptors leading to disruption index.

*Keywords: Haiti, urban disasters, reconstruction policies*

## Introduction

One year after the devastating earthquake of January 12, 2010 parts of Haiti look like the disaster struck yesterday. More than 1.5 million remain in overcrowded displacement camps, living in intolerable conditions. People of Haiti have no house to sleep in, no job, no water, poor nutrition, no money to pay for school, no medical care. The city is destroyed. The scale of the disaster as well as an unprepared disaster management system left the world stunned. No one escaped the tragedy. The level of damage and the resulting overwhelming needs are a direct result of poverty, historical context and under-development.

The social and economic situation viewed from inside did not changed a lot, with the earthquake occurrence, when compared with the situation before the event - population seem to be very resilient to adversities - they had suffered along the centuries and had been helping each other with the limited resources.

The disaster of Haiti is not the earthquake. What we are seeing here is what happens when an extreme natural event occurs in the lives of people who are already frighteningly vulnerable. No living Haitian had ever experienced an earthquake at home when the January 12 disaster crumbled their poorly constructed buildings.

This article depicts a study on the construction of a new concept named Disruption Index, with the objective to provide a systemic way to measure the earthquake impacts in urban areas, presenting the urban framework, using criteria and indicators that are important for the evaluation of existing urban spaces. Construction of this model provides governments and cities with a tool that supports their decisions related with preparedness, response, disaster management and city development.

## Seismicity and description of the earthquake

The entire Caribbean region is of high seismic activity, which is regularly ravaged by large earthquakes or volcanoes; e.g. the capital of Jamaica, Kingston was destroyed twice in three centuries and the capital of Haiti had suffered two great shocks 240 years ago (1751 and 1770). It is precisely the time distance and consequent lack of knowledge of existing earthquakes which allowed such a large number of damages. On the other hand tornadoes and hurricanes are quite normal presence in Haiti.

The earthquake resulted from a 35 km rupture (from east to west) of Enriquillo-Plantain Garden fault system, which is 500 km long (Figure 1). Its epicentre 18,457° N, 72,533° W is located about 25 km W-SW of the capital Port-au-Prince and at a depth of 13 km, but the lack of local seismic data makes the precise depth uncertain (USGS/EERI, 2010). Haiti had no seismograph stations during the main earthquake, so it is impossible to estimate accurately the intensity of ground motions. The main event was followed by two aftershocks of magnitudes 5.7 and 6, respectively. Maximum intensity in the capital and the cities of Carrefour and Delmas reached values between VIII and IX.

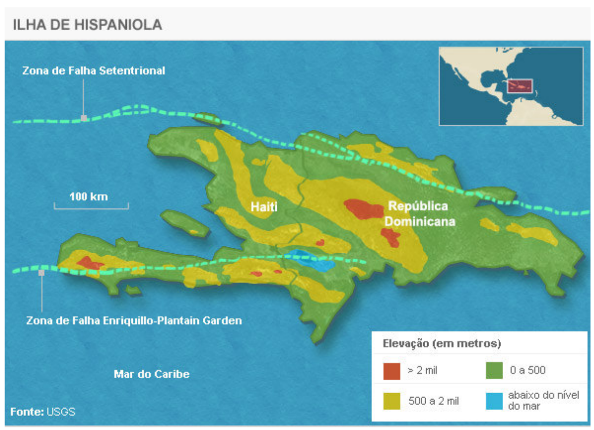


Figure 1. Geographical setting of the island of Hispaniola and Enriquillo fault

Soil liquefaction, landslides and rockslides contributed to the vast damage that occurred in Port-au-Prince and elsewhere. The damage found in houses, commerce, churches and government buildings were due mainly to inadequate construction practices, with poor material without the requirements to resist the seismic action observed - It's sub-standard construction. This is due to lack of awareness and appropriate seismic regulation.

Moreover due to the regular presence of hurricanes, the housing built since the mid $20^{th}$ century had heavy RC slabs which were good for hurricane but bad for earthquakes

## Haiti earthquake impacts

The $M_W$ 7.0 earthquake struck an already fragile Haitian society, given the political and social context over the last several years, which contributed to the disaster becoming even more tragic. At least three million people were affected by the earthquake and 250 000 buildings were destroyed or severely damaged, causing the displacement of 1.5 million people and death to 300 000 (close to 10% of the population in the metropolitan area and 3% of the country's population). There was massive destruction of all infrastructures, 80% of the capital Port-au-Prince has been reduced to rubble (105 000 houses completely destroyed and over 208 000 damaged (Taucer et al., 2010)), including 180 public buildings, among them 13 of the 15 existing ministries collapsed. The transportation infrastructure was also severely affected, including serious damage both to the airport and port facilities, the latter still not functional after one year from the earthquake. The few houses in the city that had electric power remained three weeks without electricity and recovery took three months in rural area. At least for the first 6 months power was off at night.

All these losses linked to corruption, lack of system, and the political instability that had already been going on before, turned this country's resilience to almost nonexistent, becoming completely dependent on international aid. Note that before the earthquake more than a third of Haitians had no access to safe drinking water and Haiti is the poorest country in the Western Hemisphere with an estimated 80% of its people living under the poverty line; 54% live in abject poverty (CIA, 2010).

Many communities lacked basic services such as electricity, sanitation services or access to drinking water. So the problem of code enforcement is low down on the list. Above all we witness a social catastrophe of huge proportion dominated by unemployment and hunger.

Poor construction practices have rooted within the end of French colonization when a radical cut with the traditional French construction occurred. During the 50's a constructive practice began, made with very simple materials and technology, making use of concrete blocks and concrete slabs. The existence of RC slabs comes from the need to protect buildings upon the passage of frequent hurricanes. However, the lack of knowledge on basic earthquake resistant construction and due to the fact that people were never been alerted that such disaster could occur unpredictably, this type of construction is potentially hazardous in disaster-prone areas.

Two months after the earthquake around 400 thousand people had not had any type of accommodation, nor even tents. Three and a half million Haitians, about one third of the population were supported by the UN food program. The Inter-American Development Bank has estimated the reconstruction of Haiti on 14 billion dollars.

Six months after the earthquake, on visiting the site, we are facing a similar scenario as if the earthquake had occurred the day before; government remains completely outside, abandonment is complete. The population makeshift tents with sticks, sheets, tiles and survives under inhumane health and hygiene conditions. Only 28 000 of the total 1.5 million displaced were resettled in new homes. North of the capital in Corail-Cesselesse, about 7 000 live in a tent camp located in a flood-bed, which was hit by a July storm that destroyed 344 new tents and made homeless 1,700 more people. Many of the tent-cities chosen for the homeless were located in flood plains or under the threat of landslides (http://www.hlswatch.com/page/2/), and the population are always subject to further disasters. Reconstruction of the country lacks a plan, a focus and a direction.

The emergency that in normal conditions usually takes between 3 to 7 days, in Haiti exceeded 6 months, according to statements by the Haitian Government and the UN.

Nearly half of Haiti's population (about 9 million people) are children aged up to 14 years. The earthquake left them in an extreme vulnerability due to the abandonment, loss of parents and child traffic.

Close to 97% of schools were destroyed and about 30 000 students and children died in this earthquake as well as 1 300 teachers (www.unisdr.org). 1 300 schools are demolished and 2 500 damaged (Figure 2), corresponding to around 80% of Haitian schools; severely affecting the part of the country's investment future and for an indefinite period (http://mceer.buffalo.edu/infoservice/disasters/Haiti-Earthquake-2010.asp). University College education was also affected, taking example of the country's principal Medical and Nursing Schools which collapsed (Oliveira et al., 2010).


Figure 2. Collapse of the nursing school in Port-au-Prince (left), pancake type collapse of the University of St. Gerard where 200 people died (right)

In October 2010 the country was struck by a cholera epidemic. Densely populated areas where drinking water is scarce, waste accumulates in unsuitable areas and food security is doubtful, when subject to natural disasters are prone to the bacteria's progression. The post-earthquake exodus of the population to the north of Haiti, led to an overcrowding on the banks of the Artibonite river, where people bathe, drink water and use it for their hygiene, causing an environment prone to the development of this disease that was eradicated in the country for over the past hundred years.

In addition to public health problems, lack of social services and police force/security as well as basic human rights are a continuous problem. Moreover, they were not even before; more than half of Haitians had no access to drinking water and 70% had no health-hygiene services. A year later, only 5% of the debris has been removed, and as we were able to notice, what was removed was deposited along the roads, contributing to an environmental and health impact.

**The different impact levels and consequent Disrupton index**

The analyses of real-life experiences and lessons learned from several earthquakes allowed us to select the key criteria which best describe the urban functionality and consequently to evaluate the earthquake impact in a certain area. The task of evaluating earthquake impact implies that we know fully what urban functions do and what that worth is to us.

In this section our framework is based on a novel concept: the disruption index, which characterizes and quantify the state of disorder induced by the disruption of urban structure and functions. During and after an earthquake several services are unavailable to end users, thereby causing service disruption and consequently main urban functions failure like:

• Disruption of water service for drinking/domestic use and for irrigation purposes, hampering agriculture;

• Disruption of electricity, impacting security and the provision of health and other essential services;

• Health problems (degrading health conditions), due to lack of accessibility to health services providers;

• Hindered access to and from home to jobs, markets and other communities;

• Disruption of communication within and between communities, impacting security per example;

• Increased prices of commodities and transportation;

• Disruption of communal functions (social, economic and religious) and so on.

From the above considerations, it appears clearly that a functional urban taxonomy forms the basis to evaluate the earthquake impact. Therefore functions have to be established. The functions have been classified into seven criteria or dimensions of human needs (the most fundamental: Environment, Housing, Food, Safety & Security, Health, Education and Employment). Each criterion contains the functions (service components) that have impact on welfare and urban life aspects like water, sanitation, telecommunications, power, transportation network and existence of debris. Once understood the relation between dimensions and the service components that allows that functions (Figure 3), we are able to:

1) model the different interactions within and between systems as well as the propagation effects (dysfunctions) based on Dijkstra's algorithm (1959), which is a graph search algorithm that solves the single-source shortest path problem for a graph producing a shortest path tree. With this procedure is possible to demonstrate systems, sub-systems and infrastructures with greater potential to induce a generalized dysfunction in the global system in which it is included, allowing for its prioritization by a functional point of view (Figure 4).

2) qualitatively characterize the impact (descriptors) or the expected consequences associated with the loss of functionality and identify the reference levels (I to VI, per example. Level I is the minimum or no impact level (good performance) and VI the maximum impact, the total collapse or function failure) (Table 1). In this stage we want to comprehend and visualize the consequences.

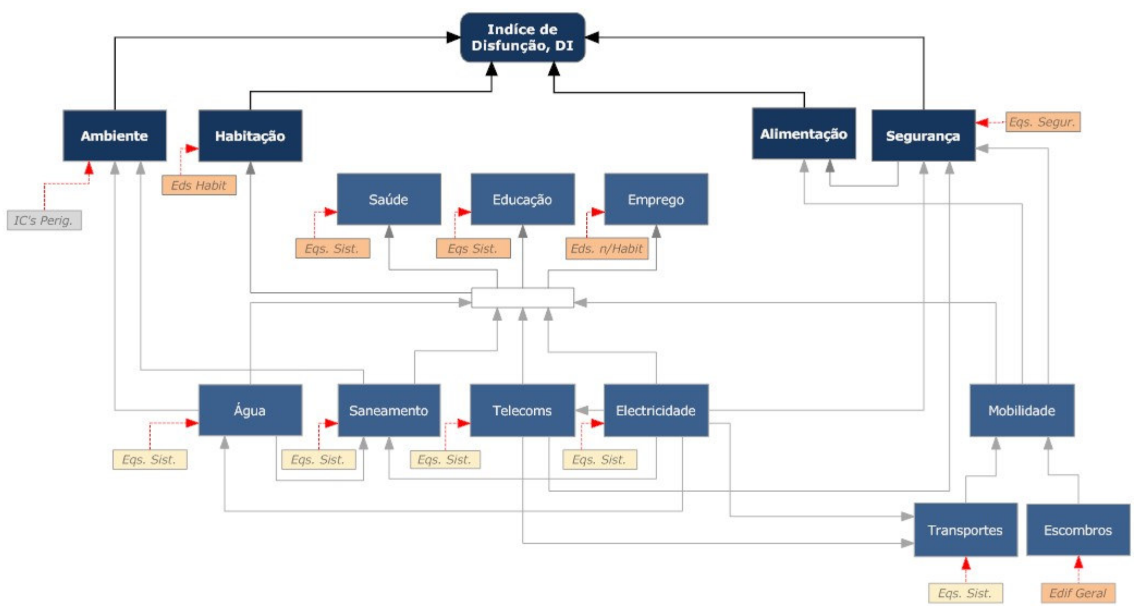


Figure 3. Vital or urban functions and their dependencies

Further information is given in Mota de Sá et al. (2011), where a detailed account on theoretical developments is presented.

| | DI | Ambiente | Alimen | Habitação | Segur | Saúde | Educação | Emprego | Mobilidade | Electricidade | Telecoms | Transportes | Escombros | Água | Saneamento | Ics Perig |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DI** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| Ambiente | | 1 | | | | | | | | | | | | 1 | 1 | 1 |
| Alimen | | | 1 | | 1 | | | | 1 | | | | | | | |
| Habitação | | | | 1 | | | | | 1 | 1 | 1 | | | 1 | 1 | |
| Segur | | | | | 1 | | | | 1 | 1 | 1 | | | | | |
| Saúde | | | | | | 1 | | | 1 | 1 | 1 | | | 1 | 1 | |
| Educação | | | | | | | 1 | | 1 | 1 | 1 | | | 1 | 1 | |
| Emprego | | | | | | | | 1 | 1 | 1 | 1 | | | 1 | 1 | |
| Mobilidade | | | | | | | | | 1 | | | 1 | 1 | | | |
| Electricidade | | | | | | | | | | 1 | | | | | | |
| Telecoms | | | | | | | | | | 1 | 1 | | | | | |
| Transportes | | | | | | | | | | 1 | 1 | 1 | | | | |
| Escombros | | | | | | | | | | | | | 1 | | | |
| Água | | | | | | | | | | 1 | | | | 1 | | |
| Saneamento | | | | | | | | | | 1 | | | | 1 | 1 | |
| Ics Perig | | | | | | | | | | | | | | | | 1 |

| | DI | Ambiente | Alimen | Habitação | Segur | Saúde | Educação | Emprego | Mobilidade | Electricidade | Telecoms | Transportes | Escombros | Água | Saneamento | Ics Perig |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DI** | 1 | | | | | | | | | | | | | | | |
| Ambiente | 1 | 1 | | | | | | | | | | | | | | |
| Alimen | 1 | | 1 | | | | | | | | | | | | | |
| Habitação | 1 | | | 1 | | | | | | | | | | | | |
| Segur | 1 | | 1 | | 1 | | | | | | | | | | | |
| Saúde | 1 | | | | | 1 | | | | | | | | | | |
| Educação | 1 | | | | | | 1 | | | | | | | | | |
| Emprego | 1 | | | | | | | 1 | | | | | | | | |
| Mobilidade | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| Electricidade | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | |
| Telecoms | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | | | |
| Transportes | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | | | | |
| Escombros | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | 1 | | | |
| Água | 1 | 1 | | 1 | | 1 | 1 | 1 | | | | | | 1 | 1 | |
| Saneamento | 1 | 1 | | 1 | | 1 | 1 | 1 | | | | | | | 1 | |
| Ics Perig | 1 | 1 | | | | | | | | | | | | | | 1 |

Figure 4. Dependency matrix (left) and propagation matrix (right)

Table 1. Criteria and respective consequence descriptors

| Criteria | Descriptors |
|---|---|
| Environment | Assesses the environmental impacts due to soil contamination, water, aquifer or spills. It also assess the impact of service disruption of urban hygiene/public health from debris storage (building materials, personal property, and sediment from mudslides), contamination of water (unsafe drinking water and sanitation) and the high concentration of people in the same space. |
| Housing | Evaluates whether a particular area may or may not be occupied for housing function as a result of the damage. |
| Food | Evaluates if the food is accessible to the majority of the population and identify alternatives to their supply (coping strategies). |
| Safety & Security | Evaluates the level of security (people, property, businesses, etc) in a particular area. |
| Health | Determines if the population is served by a sufficient number of health facilities. |
| Education | Measures the discontinuity of education, the number of people without school lessons and identifies alternatives for the recovery. |
| Employment | Evaluates whether a certain area retains its activity as a result of the damage after the earthquake and identify new clusters of jobs that can be generated. |

As highlighted before each descriptor have different levels of performance. Figure 5 partially shows the descriptor impact for Housing criteria with corresponding impact level.

| **Habitação** | |
|---|---|
| **Nível de Impacto** | **Descritor de impacto**<br>*Avalia se determinada área pode ou não ser ocupada para a função habitação em consequência dos danos ocorridos e indica alternativas quando a habitação/abrigo não existe.* |
| VI | Abandono definitivo. |
| V | População necessita ser relocalizada por tempo indeterminado. |
| IV | Habitações parcialmente inutilizáveis, provocam o realojamento prolongado em tendas ou outras habitações temporariamente. |
| III | Habitação condicionada. Eds. com danos ligeiros ou com acesso condicionado devido a escombros. Necessário realojamento temporário ou prolongado. |
| II | Habitação com danos ligeiros. Reparações/reforço são efectuados muitas vezes com a população a viver dentro das habitações, sem necessidade de as realojar por tempo indeterminado. No entanto, há um realojamento temporário, após o evento, até estarem definidas as estratégias de reparação/reforço. |
| I | Condições originais |

Figure 5. Level of performance

In sequence and using the outputs of the damage estimation models (simulators) or a earthquake description as we have in Haiti and due to the fact that we face a complex “network” we solved the problem using logical conditions (combines the results of two or more component conditions to produce a single result based on them) to evaluate the earthquake impact. The benefit of use logical conditions is that we don’t need to use hypothetical utility functions and weights.

The next Figure shows an example:

| Saneamento | | | | | | | |
|---|---|---|---|---|---|---|---|
| Nível de Impacto | **Descritor de impacto.** *Mede o constrangimento devido à interrupção de infraestruturas de saneamento e consequentemente o seu reflexo nas condições de higiene* | | Forn. Electr | | Fornec. Água | | Equips. Sist San. |
| V | Destruição das Infraestruturas. Interrupção de serviço por tempo indeterminado. | | > IV | OR | > IV | OR | > III |
| IV | Interrupção de Serviço por tempo prolongado | | > III | OR | > III | OR | > II |
| III | Interrupção de serviço temporária. | | > II | OR | > II | OR | > I |
| II | Serviço sem interrupção significativa ou sem interrupção. | | > I | OR | > I | OR | > I |
| I | Serviço em funcionamento normal | | - | - | - | - | - |

Figure 6. Logical condition to obtain the impact level of each function

Next figures show how to use this model to the case of Haiti. On Figure 7 the yellow cells translate the impact level observed to each equipment (or component of the criteria) after the earthquake. By the use of logical conditions (as shown in Figure 6) we could calculate to each criteria, its impact level (Figure 8) and consequently obtain the disruption level (Figure 9) imposed by an event in a certain area.

| | | |
|---|---|---|
| 4 | [ 1...4 ] Equipamentos do sistema de Energia Eléctrica | Destruição das Infraestruturas.Necessidade de reconstrução de grandes infraestruturas |
| 3 | [ 1...4 ] Equipamentos do sistema de Transportes | Danos severos nas vias estruturantes |
| 4 | [ 1...4 ] Equipamentos do sistema de Água | Grandes reparações. Tempo de reposição superior a 6 meses |
| 4 | [ 1...4 ] Equipamentos do sistema de Saneamento | Grande Destruição. Serviço com interrupção generalizada e por tempo indeterminado |
| 4 | [ 1...4 ] Equipamentos do sistema de Telecomunicaçõe | Grande Destruição. Serviço com interrupção generalizada e por tempo indeterminado |
| 5 | [ 1...5 ] Equipamentos de ensino | Colapso total ou parcial. Inutilizáveis |
| 5 | [ 1...5 ] Equipamentos de saúde | Colapso total ou parcial. Inutilizáveis |
| 5 | [ 1...5 ] Equipamentos de segurança | Colapso total ou parcial. Inutilizáveis |
| 4 | [ 1...5 ] Edifícios de Habitação | Danos severos. Inutilizáveis |
| 4 | [ 1...5 ] Edifícios não habitacionais | Danos severos. Inutilizáveis |
| 4 | [ 1...5 ] Edificado geral | Danos severos. Inutilizáveis |
| 1 | [ 1...4 ] Ocorrências em IC's Perigosas | Sem danos |

Figure 7. Level of dysfunction of each equipment or network

| Level | Critera | Descriptor |
|---|---|---|
| 3 | [ 1...5 ] Ambiente | Perturbação de ordem sanitária, com degradação significativa da saúde pública |
| 5 | [ 1...6 ] Habitação | População necessita ser relocalizada por tempo indeterminado. |
| 3 | [ 1...3 ] Alimentação | Interrupção do seu fornecimento por tempo indeterminado, o que gera uma indisponibilidade inaceitável. |
| 5 | [ 1...5 ] Segurança | Forças de segurança insuficientes ou severamente afectadas. Incapacidade de repor ordem, segurança e soco |
| 5 | [ 1...5 ] Educação | Impossibilidade de retomar o ensino por tempo indeterminado (obras de reabilitação/reconstrução). Relocali sismo. |
| 5 | [ 1...5 ] Emprego | Interrupção da actual actividade económica por tempo indeterminado (falta de oportunidades). No entanto, s que a maior parte das vezes os trabalhadores são oriundos de outras localidades ou países. |
| 4 | [ 1...4 ] Saúde | Inutilização de unidades de saúde, tendo de recorrer-se a hospitais de campanha, apoio exterior, etc. |
| 5 | [ 1...5 ] Fornecimento de Energia Eléctrica | Destruição das Infraestruturas. Interrupção de serviço por tempo indeterminado. |
| 5 | [ 1...5 ] Abastecimento de Água Potavel | Destruição das Infraestruturas. Interrupção de serviço por tempo indeterminado. |
| 5 | [ 1...5 ] Saneamento | Destruição das Infraestruturas. Interrupção de serviço por tempo indeterminado. |
| 5 | [ 1...5 ] Serviços de Telecomunicações | Destruição das Infraestruturas. Interrupção de serviços de Comunicações, Internet e Dados por tempo indeter Serviços e Infraestruturas Críticas. |
| 4 | [ 1...4 ] Mobilidade | Fortemente perturbada a nível regional e local |
| 5 | [ 1...5 ] Transportes (Rodov.) | Destruição das Infraestruturas. Interrupção de eixos ou acessos regionais fundamentais por tempo indetermir |
| 4 | [ 1...4 ] Acumulação de Escombros | Acumulação generalizada de grandes quantidades de escombros com forte perturbação da circulação (auto ou |

Figure 8. Level of dysfunction of each function (services) and associated criteria

| Level | | |
|---|---|---|
| 5 | **[ 1...5 ] Índice de Disfunção, DI** | Graves perturbações a nível físico e funcional a paralisia de todo o sistema: edificações, popul mobilidade, estruturas administrativas e políticas, entre outras. Inexistência de condições pa actividades do quotidiano. Recuperação penosa e custos avultado |

Figure 9. Measuring the disruption

The present methodology has arrived to a value of the disruption index (DI) equal to 5, which means “From serious disruption at physical and functional level to paralysis of the entire system: buildings, population, infrastructure, health, mobility, administrative and political structures, among others. Lack of conditions for the exercise of the functions and activities of daily life. High cost for recover.” This index was computed for a time ($t_0$) right after the event. It can be equally computed for any other time after the event, incorporating the recovery process, looking at the impact as a function of time.

## Conclusions and outlook

Being aware of the likely impacts of future hazards, communities will be able to take decisions, and to plan appropriate strategies to reduce their losses and protect their livelihood systems including infrastructure. All development plans should be based on disaster mitigation concepts.

Unless we carefully guide the process of urbanization (the growth of cities in developing world) and reconstruction processes, a sustainable, resilient and earthquake disaster reduction will remain elusive. Appropriate attention should be given to self-build “shanty-towns” or “bidonvilles” and urban low-rise buildings that are a very common feature in most cities of developing countries - it’s of main importance to educate and to adapt the existing methods of construction to curb the risks and vulnerabilities that particularly poor societies face. But it is not only the application of building construction technology that will reduce the risk, geological and topographical examination with the purpose of micro-zoning the earthquake-prone areas, should be used to modify population occupancy and to modify construction standards. Another aspect to be underlined is the inexistence of building construction legislation and when exists how effective can be. Legislation is insufficient without regular, strategic, informed and reliable inspection to ensure its enforcement.

The presented disruption index (DI) is a powerful tool which can be applied to any kind of earthquake situation, using real data (descriptive) or data obtained from earthquake simulators and allowing the comparison among different earthquake scenarios.

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